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Preliminary Report - TWO YEAR GROWTH AND BIOMASS YIELD OF HYBRID POPLAR

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ABSTRACT

Hybrid poplar is being investigated at the farm of David Smith, Port Ryerse, to determine its potential as a renewable and dependable source of fuel energy for a greenhouse operation. In May of 1984, six clones of hybrid poplar were planted. After two years of growth, the main stem diameter of the different clones ranged from 1.6 cm to 3.1 cm, while the main stem height ranged from 175 cm to 361 cm. In April of 1986, the clones were harvested with a modified corn forage harvester. The moisture content of the tree biomass at harvest ranged from 55% to 61% (w.b.). The biomass yield of the different clones ranged from 2.10 oven dry tonnes/ha to 7.69 oven dry tonnes/ha. Monitoring will be continued to determine the regenerative growth of the hybrid poplar and biomass yield of future harvestings.

INTRODUCTION

In Ontario, the production of vegetables (tomatoes/cucumbers) in greenhouses is heavily dependent upon petroleum based energy sources for heating. Approximately 99% of Ontario's greenhouse vegetable production is heated by heavy or light oil, natural gas and propane. Less than 1% of greenhouse vegetable production is heated with wood (Fisher 1986).

David Smith of Port Ryerse operates a greenhouse tomato operation that is heated with various types of forestry residue. The primary fuel source is sawdust @ 32% m.c. (w.b.). At an average cost of $11.50 per tonne of sawdust, heating costs average $12,000 per year for two crops of tomatoes harvested from 2 200 m^2 of greenhouse. Heating the same area with natural gas or oil would cost 2 - 3 times more.

Problems associated with using sawdust as a fuel are: insecure supply; increased demand; and rising prices. In conjunction with the high cost of petroleum based fuels and poor returns for cash crops, David decided to grow and harvest his own energy in the form of hybrid poplar.

Poplars are one of the fastest growing trees in Canada. Research by the Ontario Ministry of Natural Resources indicates that intensively managed poplar plantations have the potential to produce 10 oven dry tonnes of tree biomass per hectare per year. In cooperation with the Ontario Ministry of Natural Resources, David planted a test site of hybrid poplar at his farm to determine its potential as a renewable and dependable source of fuel energy for his greenhouse operation.

Poplar Culture in Ontario

In Ontario, poplar breeding research began in the mid - 1930's. Based on the success of the breeding research, a poplar plantation management program was initiated in 1969 by the Ontario Ministry of Natural Resources and Domtar Incorporated. The objective of the program was to determine the biomass potential of hybrid poplar for the pulp industry. The program studied the growth and yield of hybrid poplar planted 3 m apart in rows spaced 3 m and harvested 10 years later. The results were encouraging and led to the formation of the hybrid poplar management program established in the Eastern Region of the Ontario Ministry of Natural Resources.

The hybrid poplar program is concentrating on improving the technology of poplar biomass production. A variety of management areas are being investigated: clone selection; site selection and preparation; clone to site allocation; tree spacing; weed control; pest control; fertilization and irrigation.

Three types of plantations are being studied: short, medium and long rotations. Under intensive management, the short rotation appears to have the greatest yield potential for biomass production. A short rotation has a tree density of approximately 35 000/ha and is harvested every 2 - 3 years. Medium and long rotations have tree densities of 4 000/ha and 1 000/ha, respectively. A medium rotation is harvested every 5 - 7 years, while a long rotation is harvested every 8 - 12 years. After the initial harvest of each plantation, subsequent biomass production depends on the growth and quanity of multiple stems (coppices) regenerating from the original stumps.

OBJECTIVES

In cooperation with David Smith and the Ontario Ministry of Natural Resources, the Agricultural Energy Centre of the Ontario Ministry of Agriculture and Food is monitoring the hybrid poplar site at the Smith farm to determine:

1/tree growth;

2/tree biomass production;

3/heat energy content of tree biomass.

PROJECT DESIGN

Clone Selection - Six clones of hybrid poplar were selected for planting.

Species or Hybrid	Ontario Code	Country of Origin
Populus x *euramericana*	'DN 22'	Italy
Populus deltoides x *nigra*	'DN 112'	Canada
Populus angulata x *berolinensis*	'DTAC 1'	U. S.
Populus deltoides x *trichocarpa*	'DTAC 7'	Belgium
Populus nigra x *maximowiczii*	'NM 1'	Japan
Populus nigra x *maximowiczii*	'NM 6'	West Germany

Clone selection was based on the climate of the Port Ryerse area and the following:

site size - 2.2 ha
soil type - silty clay loam, poorly drained (soil profile in Appendix I)
length of rotation - 2 - 3 years
planting density - 35 000/ha

Site Preparation and Planting

The 2.2 ha site had previously been cropped with soybeans. Prior to soil preparation, Roundup was applied for weed control. In the spring of 1984 the site was disced, divided into 14 blocks and randomly planted with 6 poplar clones.

As illustrated in Figure I, unrooted cuttings, 25 cm long by 10 mm to 20 mm in diameter, were planted during May of 1984 with a modified potato planter. The cuttings were to be planted 0.3 m apart in rows spaced 1.0 m for a planting density of approximately 33 000/ha, however, spacing between the cuttings was difficult with this type of planter. The actual spacing ranged from 0.30 m to 0.36 m and resulted in a planting density of 28 000/ha to 33 000/ha. Table I lists the clone to block allocation, block size and number of rows per block.

Tending Practices

The tending practices employed during the first growing season were as follows:

weed control - chemical: 2.2 kg/ha of Sinbar, not incorporated and applied to all blocks except G
- mechanical: one inter-row cultivation at time of fertilizer application to all blocks
fertilizer - sidedress 112 kg/ha of 15-15-15 to all blocks
pest control and irrigation - none

During the second growing season, Sinbar was applied at a rate of 2.2 kg/ha to block G. No other tending practices were employed.

Harvesting The clones were mechanically harvested from April 26 - 30, 1986. A corn forage harvester, as illustrated in Figure II was utilized to fell, chip and blow the chips into a forage wagon which trailed behind the harvester. The harvester was pulled and powered by a 55 kW tractor.

The corn forage harvester was originally a two-row machine that was modified into a one-row. Modifications included mounting a carbide-tip saw blade underneath the gathering chains at the front-end of the harvester. The saw blade rotated by a belt running from the main drive shaft of the harvester cut the poplars 8 cm to 10 cm above the soil surface. The trees were pulled into the harvester by the gathering chains and a bar mounted at the top end of the gathering chains deflected the trees into the cutter bars of the harvester. The cutter bars chipped the trees into pieces ranging from 0.5 cm to 3.0 cm long and 0.5 cm to 1.0 cm thick. The chips were blown into the forage wagon trailing behind the harvester.

DATA COLLECTION

Tree Growth

The main stem diameter and main stem height of the trees in each block were measured on June 7, 1985 and April 1, 1986. A 3m x 3m area, 40 m into each block, served as the sampling site. The main stem diameter of each tree in the sample area was measured with calipers 8 cm to 10cm above the soil surface. The main stem height of each tree was measured from the base of the tree at the soil surface to the tip of its longest stem.

Tree Biomass Yield

The tree biomass harvested from each block was weighed with portable axle scales. Samples of the tree biomass were collected for moisture content analysis. An oven dry method of 105°C for 24 hours was used to calculate the initial moisture content and the oven dry yield of the tree biomass from the various clones.

Heat Energy Content of Tree Biomass

The heat energy content of the tree biomass was determined by the oxygen bomb calorimeter method described in Appendex II.

RESULTS

Main Stem Diameter and Height

Table II contains main stem diameter and height measurements recorded on June 7, 1985. The main stem diameter ranged from 1.1 cm for clone 'DN 22' in block N to 2.1 cm for clone 'DTAC 7' in block J. The main stem diameter of similar clones (excluding 'DTAC 7') in different blocks did not vary by more that 0.5 cm.

The main stem height ranged from 78 cm for clone 'NM 6' in block G to 212 cm for clone 'NM 1' in block D. However, clone 'NM 6' in block G did not have an application of herbicide during the first growing season and was definately affected by weed competition. As compared to blocks F and H which were planted with the same clone, the main stem height in block G was 104 cm less.

Figure III illustrates the growth of the hybrid poplar after 2 growing seasons. Table III contains main stem diameter and height measurements recorded on April 1, 1986. The main stem diameter ranged from 1.6 cm for clone 'NM 6' in block G to 3.1 cm for clone 'DN 112' in block C. Again, the effects of not applying herbicide to plot G during the first growing season is evident. Clone 'NM 6' in block G was approximately 1 cm less in diameter than the stems in blocks F and H planted with the same clone. The main stem diameter of similar clones (excluding 'DTAC 7') in different blocks that had herbicide applied during the first growing season did not vary by more than 0.2 cm.

The main stem height ranged from 261 cm for clone 'DN 22' in block N to 361 cm for clone 'NM 6' in block A. Again, clone 'NM 6' in block G was the exception with a main stem height of 175 cm which was approximately 150 cm less in height than clone 'NM 6' in blocks F and H. The main stem height of similar clones (excluding 'DTAC 7') in different blocks that had herbicide applied during the first growing season did not vary by more than 41 cm.

MOISTURE CONTENT, YIELD AND HEAT ENERGY CONTENT OF TREE BIOMASS

Table IV summarizes the yield, moisture content and heat energy content of the different clones.

At harvest, the moisture content of the clones ranged from 55% to 61% (w.b.). The largest variation in moisture content was between blocks D and I which contained clone 'NM 1'. the moisture content of clone 'NM 1' in block D was 61% (w.b.) as compared to 55% (w.b.) in block I. Excluding clone 'NM 1', the moisture content of similar clones in different blocks did not differ by more than 2%.

The oven dry (OD) yield of the tree biomass ranged from 2.10 tonnes/ha for clone 'DN 22' in block N to 7.69 tonnes/ha for clone 'NM 1' in block D. The greatest variation in yield between blocks containing the same clone was clone 'DN 22' in blocks N and E. Block E yielded 5.61 OD tonnes/ha which was 3.5 OD tonnes/ha more than the yield of block N. The variation in yield could possibly be due to a difference in the soil type or drainage between the two blocks. Excluding clone 'DN 22', the other clones yielded between 5.03 OD tonnes/ha and 7.69 OD tonnes/ha.

Unfortunately, clone 'DTAC 7' in block J and clone 'NM 1' in block K were harvested together. The average yield of the clones was 6.15 OD tonnes/ha, however, it should not be interpretted as representative of either clone.

Due to the block design, blocks F, G and H containing clone 'NM 6' were also harvested together. It was anticipated that block G which did not have any herbicide applied during the first growing season would yield considerably less than the other blocks, however, this assumption could not be verified.

The energy content of the biomass (reported at 0% moisture content) ranged from 18 900 kJ/kg to 21 000 kJ/kg. The variation in energy content between identical clones in different blocks can be attributed to the sampling method.

DISCUSSION

Direct burning of wood at 55% to 61% moisture content (w.b.) gives off less than half as much heat as dried wood and lowers furnace efficiency because a portion of the heat energy is required to vaporize the water. Thus, felling and chipping hybrid poplar in one operation creates an additional operation of drying the chips naturally or artificially before burning.

Based on the biomass yield of clone 'NM 1' in block D, 7.69 OD tonnes/ha, lets assume that this yield could be duplicated on a larger scale. Knowing that 1 043 tonnes of sawdust at 32% moisture content (w.b.) is consumed per year ($12 000/y ÷ $11.50/t) to heat 2 200 m^2 of greenhouse on the Smith farm, approximately 177 ha of clone 'NM 1' would have to be grown and harvested every two years to replace the sawdust fuel (calculation in Appendix III). However, before this assumption can be verified, the biomass yield of subsequent harvestings will have to be monitored.

SUMMARY

1/ Good weed control during the first growing season is critical to the establishment and growth of hybrid poplar.

2/ After two growing seasons, the main stem diameter and main stem height of the six hybrid poplar clones (which had herbicide applied during the first growing season) ranged from 2.4 cm to 3.1 cm and 261 cm to 361 cm, respectively.

3/ The moisture content of the hybrid poplar biomass at harvest varied from 55% to 61% (w.b.).

4/ Direct burning of hybrid poplar chips at 55% to 61% moisture content (w.b.) is inefficient. The chips must be dried down before burning.

5/ The oven dry yield of the 2 year old hybrid poplar biomass ranged from 2.10 tonnes/ha to 7.69 tonnes/ha.

6/ The energy content of the hybrid poplar biomass (@ 0% m.c.) ranged from 18 900 kJ/kg to 21 000 kJ/kg.

7/ Based on a biomass yield of 7.69 OD tonnes/ha, approximately 177 ha of clone 'NM 1' would have to be grown to replace 1 043 tonnes of sawdust that is consumed annually to heat 2 200 m^2 of greenhouse at the Smith farm.

8/ Monitoring of the six hybrid poplar clones will have to be continued to determine the biomass yield of subsequent harvestings.

REFERENCES

Fisher, G. A. 1986. Greenhouse vegetable statistics - production areas, yields and returns for Ontario. Economics and Policy Coordination Branch - Ontario Ministry of Agriculture and Food. Chatham, Ontario, April, 1986.

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Figure I: Unrooted hybrid poplar cuttings.

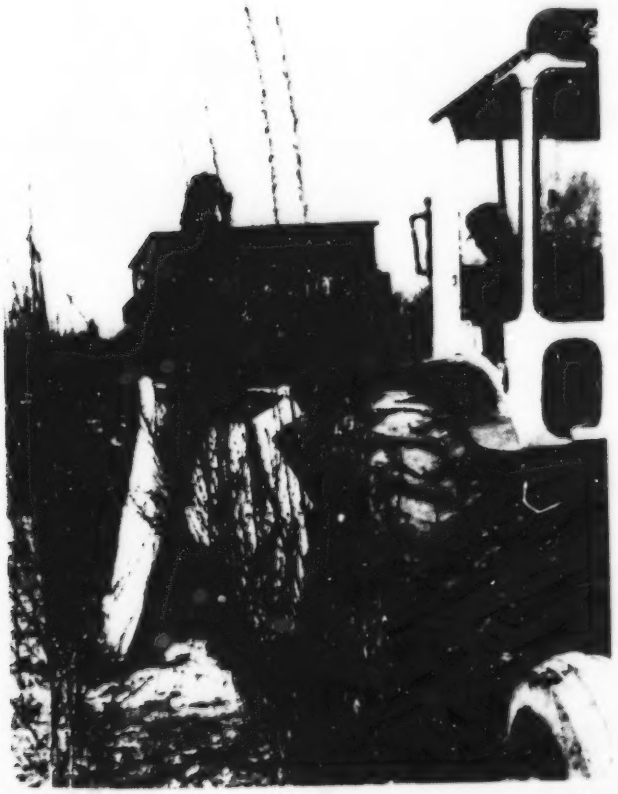

Figure II: Harvesting hybrid poplar using a modified corn forage harvestor.

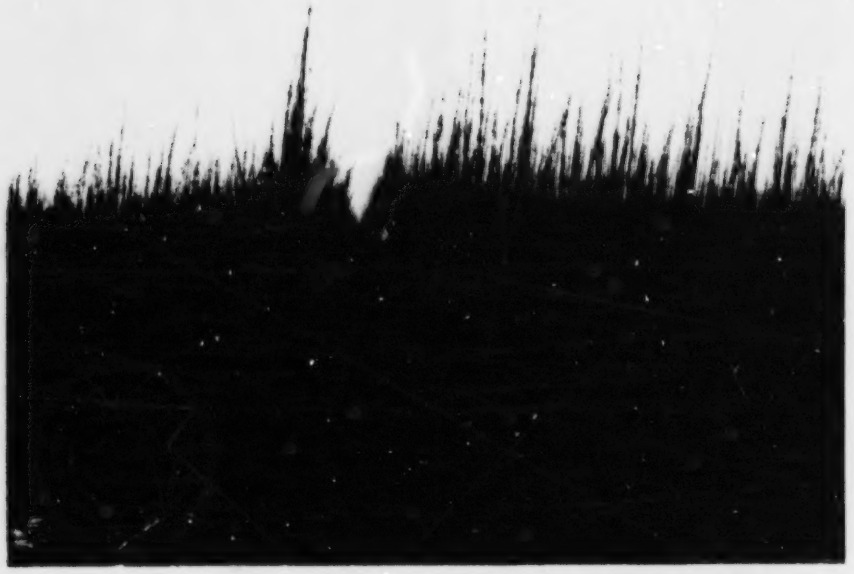

Figure III: Hybrid poplar growth after 2 years.

TABLE I: Clone to Block Allocation

Block	Clone	Rows	Area - m^2
A	'NM 6'	12	2 200
B	'DTAC 1'	12	1 800
C	'DN 112'	12	1 800
D	'NM 1'	12	1 900
E	'DN 22'	12	1 900
F	'NM 6'	3	500
G	'NM 6'	6	900
H	'NM 6'	5	800
I	'NM 1'	12	1 900
J	'DTAC 7'	9	1 400
K	'NM 1'	3	500
L	'DTAC 1'	12	1 900
M	'DN 112'	12	2 000
N	'DN 22'	16	2 400

TABLE II: Main Stem Diameter and Height, June 7, 1985

Clone	Block	Average Main Stem Diameter* (cm)	Average Main Stem Height* (cm)	Density* (Trees/ha)
'NM 1'	D	1.5	212	19 000
	I	1.9	154	20 000
	K	1.4	183	18 000
'NM 6'	A	1.3	209	27 000
	F	1.4	182	23 000
	G (no herbicide 1st year)	1.2	78	21 000
	H	1.5	182	21 000
'DN 22'	E	1.2	185	22 000
	N	1.1	143	21 000
'DN 112'	C	1.8	187	17 000
	M	1.6	167	14 000
'DTAC 1'	B	2.0	204	23 000
	L	1.7	183	17 000
'DTAC 7'	J	2.1	161	13 000

*sample area 3m x ?m

TABLE III: Main Stem Diameter and Height, April 1, 1986

Clone	Block	Average Main Stem Diameter* (cm)	Average Main Stem Height* (cm)	Density* (Trees/ha)
'NM 1'	D	2.8	331	19 000
	I	2.5	299	20 000
	K	2.6	293	18.000
'NM 6'	A	2.5	361	27 000
	F	2.6	342	23 000
	G (no herbicide 1st year)	1.6	175	21 000
	H	2.7	320	21 000
'DN 22'	E	2.6	297	22 000
	N	2.4	261	21 000
'DN 112'	C	3.1	297	17 000
	M	3.0	304	14 000
'DTAC 1'	B	2.7	326	23 000
	L	2.8	339	17 000
'DTAC 7'	J	2.8	285	13 000

*sample area 3m x 3m

TABLE IV: Moisture Content, Yield and Heat Energy Content of Each Clone*

Clone	Block	%Moisture Content (w.b.) at Harvest	Oven Dry Yield (tonnes/ha)	Heat Energy Content (kJ/kg)
'NM 1'	D	61.3	7.69	19 800
	I	55.4	6.48	21 000
'NM 6'	A	59.3	6.43	20 800
	F, G, H	59.7	6.42	21 100
'DN 22'	E	56.7	5.61	20 700
	N	56.6	2.10	19 800
'DN 112'	C	56.5	5.88	20 500
	M	56.2	5.53	20 000
'DTAC 1'	B	57.2	6.72	20 500
	L	58.9	5.03	18 900
'DTAC 7' & 'NM 1'	J, K	56.3	6.15	20 700

*harvested April 26 - 30, 1986

Appendix I: Soil Profile Description

HORIZON		Ap	Bg1	Bg2	Ckg
DEPTH (cm)		0-27	27-70	70-90	90+
TEXTURE		Silty Clay Loam (SiCL)	SiCL	Silty Clay (SiC)	SiC
STRUCTURE	Grade	Moderate	Moderate	Strong	Strong
	Kind	Sub-angular blocky	Sub-angular blocky	Sub-angular blocky	Sub-angular blocky
	Class	Medium	Coarse	Coarse	Coarse
CONSISTENCE	Stickiness	Slightly Sticky	Slightly Sticky	Sticky	Sticky
	Plasticity	Slightly Plastic	Slightly Plastic	Plastic	Plastic
	Moist	Friable	Firm	V. Firm	V. Firm
CEMENTATION		-----	-----	-----	-----
NOTTLES	Abundance	-----	Common	Many	Common
	Size	-----	Medium	Medium	Fine
	Contrast	-----	Prominent	Prominent	Distinct
DRAINAGE CLASS	Poorly Drained				
ROOTS	Abundance	Many	Few	Few	Very Few
	Diameter	Fine	Fine	Very Fine	Very Fine
	Orientation	Random	Oblique	Oblique	Vertical
	Species	Soybeans	Soybean	Soybean	Soybean
PORES	Abundance	Common	Few	Few	Few
	Diameter	Fine	Fine	Fine	Fine
pH		6.0			
ORGANIC MATTER		3.1			

Appendix II: Procedure For Oxygen Bomb Calorimeter

1. Prepare a 1.0 g sample into a pellet form and place it into a weighed crucible. Reweigh.

2. Fasten a 10-cm length of fuse wire between the two electrodes. Place the fuel capsule in the electrode loop and bend the wire downward so that the loop bears against the top of the pellet.

3. Add 1 mL of distilled water from a pipet in the bottom of the bomb.

4. Moisten the sealing ring with a bit of water, then slide the head into the cylinder and push it down as far as it will go. Hand tighten ring.

5. Add 20 atmospheres of oxygen slowly.

6. Fill the calorimeter bucket with 2000 (± 0.5) grams of water. Place in calorimeter. Lower the bomb in the water and push the two ignition lead wires into the terminal sockets on the head.

7. Close the calorimeter cover. Check to make sure the thermometer is not going to break when moving lid. Lower the thermometer bracket and start motor.

8. Let run 4 or 5 minutes while the controller brings the jacket temperature to equilibrium with bucket temperature.

9. Read and record thermometer (bucket) and then ignite holding it down until the indicator light goes out.

10. Start temperature readings at about 5 minutes after firing until it reaches a stable maximum. Record temperature.

11. Raise thermometer and open cover. Remove bomb and relaease pressure slowly.

12. Wash all interior surfaces of bomb with water and collect washings.

13. Remove all unburned fuse wire and measure. Subtract this length from 10 cm and record this quantity.

14. Titrate the bomb washings with standard sodium carbonate using methyl orange as the indicator (.0709 N).

Calculations

Standardization Procedure (benzoic acid)

$$W = \frac{Hm + e_1 + e_3}{t}$$

W = energy equivalent of the calorimeter in cal/°C

H = heat of combustion of benzoic acid in cal/g (6318)

m = mass of benzoic acid in grams

t = net corrected temperature rise in °C

Appendix II continued

e_1 = correction for heat of nitric acid in cal = (mL titrated x 1 cal/mL)

e_3 = correction for heat of the firing wire = (cm wire x 2.3 cal/cm)

Gross Heat of Combustion

$$Hg = \frac{tW - e_1 - e_3}{m}$$

t = temperature final corrected minus temperature intial corrected

W = energy equivalent of calorimeter in calories/°C

e_1= correction in cal for nitric acid - 1 mL = 1 cal

e_3= correction in cal for fuse wire 2.3 cal/cm

m = mass of sample in g

Hg = gross heat of combustion in cal/g

Appendix III: Hectares of Hybrid Poplar Required to Heat 2 200 m^2 of Greenhouse

Sawdust Consumption

known - 1043 tonnes of sawdust @ 32% m.c. (w.b.) per year to heat 2 200 m^2 of greenhouse
- equivalent to 709 oven dry tonnes/year
- measured heating value of sawdust, 19.0×10^6 J/kg @ 0% m.c.

energy equivalent of sawdust = 709 OD tonnes/y x 1000 kg/tonnes x 19.0×10^6 J/kg
= 1.35×10^{13} J/y

Hectares of Hybrid Poplar Required to Heat 2 200 m^2 of Greenhouse

known - clone 'NM 1' in block D yielded 7.69 oven dry tonnes/ha after 2 years which is equivalent to 3.85 oven dry tonnes/ha per year
- measured heating value of clone 'NM 1' in block D, 19.8×10^6 J/kg @ 0% m.c.

assume- moisture content of hybrid poplar when burned is equivalent to sawdust

$$\text{hectares required of clone 'NM 1'} = \frac{1.35 \times 10^{13} \text{ J/y}}{3.85 \text{ OD t/ha/y} \times 1000 \text{ kg/t} \times 19.8 \times 10^6 \text{ J/kg}}$$

= 177 ha